July 1951

Radar Tracks Shooting Stars

Using radar echoes, the speeds of meteors coming from outer space are recorded at 100,000 miles per hour

By PROF. A. C. B. LOVELL and J. G. DAVIES*

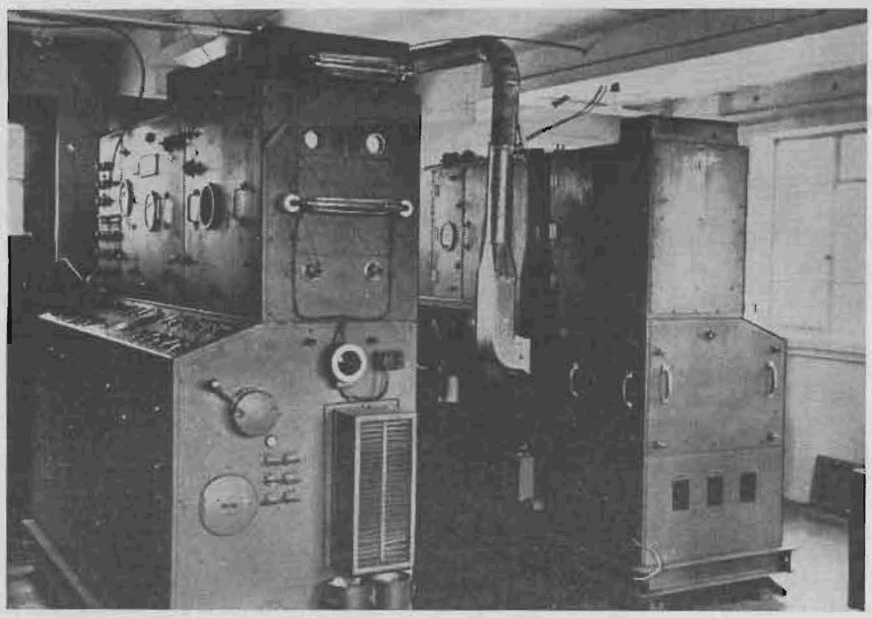

Fig. 1—Search transmitter at Cheshire, England, uses ex-army radar equipment.

METEORS, or "shooting stars," are tiny pieces of stone or iron which rush into the earth's atmosphere at speeds thousands of times faster than an express train. Fortunately for us they get very hot by friction in the highest layers of the atmosphere and burn up. They rarely penetrate lower than about 50 miles above the earth's surface. In this process of evaporating they leave a trail of light several miles long.

Until recently the visual or photographic study of these meteor trails was the only way to obtain information about them. Although they could not be observed in daylight, and although their study was severely handicapped by cloud or bright moonlight, we knew that 100,000 millions of these pebbles were pouring into the earth every 24 hours. We also knew that occasionally the earth rushed through an extraordinary concentration of this debris, producing what is known as a meteor shower. But in spite of more than 100 years of observation the astronomers do not know for certain where these vast numbers of pebbles come from.

During the last few years radio has been used to study these meteors and several of the outstanding problems are beginning to be solved. In this article we shall describe some of the basic radio techniques which are now in use.

Meteor detection by radio

When the meteor burns away in the high atmosphere it leaves behind for a very short time a dense trail of electrons, as well as the streak of light by which we see it. This electron trail enables us to detect the meteor by radio. The fundamental process is very simple. A radio wave sets the electrons in the trail into vibration, and while they are oscillating they reradiate a small amount of the energy in the incident radio wave. This energy will travel back toward the earth, and if we have a sensitive enough receiving set, we can detect these radio waves which are scattered from the trail. Both pulse and c.w. methods are used. The frequencies used are generally higher than 20 mc, otherwise one gets trouble from the reflections from the ionized E and F regions, and the results are difficult to interpret.

There are many more faint meteors than bright ones. Thus the more sensitive the apparatus the more meteors will be detected. For example, in a pulse equipment, using a peak transmitter power P, an aerial with a power gain G, a receiver note factor ε, and a wavelength λ, it can be shown that the faintest meteor detectable will depend on: $G\sqrt{\frac{P\lambda^3}{\varepsilon}}$

In this article we shall first describe a pulse apparatus working on 72 mc in which the transmitter power and receiver sensitivity were such that the number of echoes seen corresponded very closely with the number of meteors which could be seen by a single visual observer on a clear night.

72-mc pulse apparatus

In this apparatus—now in use at the Jodrell Bank Experimental Station in Cheshire, England—an ex-army radar transmitter forms the basis of the meteor transmitter shown in Fig. 1. The transmitter consists of an oscillator stage with two British Service tubes, type VT-98 triodes (Fig. 2). These run

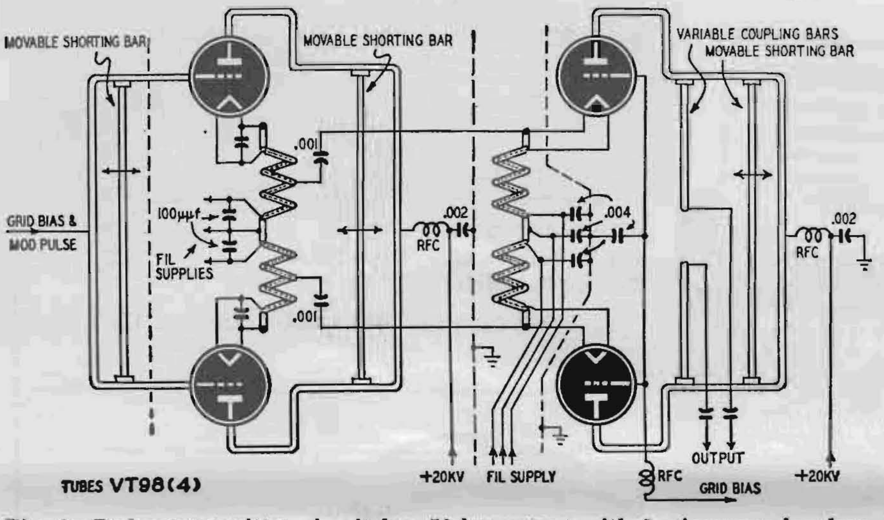

Fig. 2—Radar transmitter circuit has 50-kw output with 8-microsecond pulses.

---

*Jodrell Bank Experimental Station (University of Manchester) Cheshire, England.

at 20 kv on the plates and are tuned with resonant lines in the plate and grid circuits. The oscillator is cathode-coupled to a grounded-grid amplifier stage of two similar tubes, and the output is tapped off the plate lines. This transmitter gives a peak power of about 50 kw for 8-microsecond pulses at a repetition frequency of 600 pulses per second. The filament supplies are fed to the cathodes via coaxial ("unity-coupled"—*Editor*) chokes, which also act as coupling transformers.

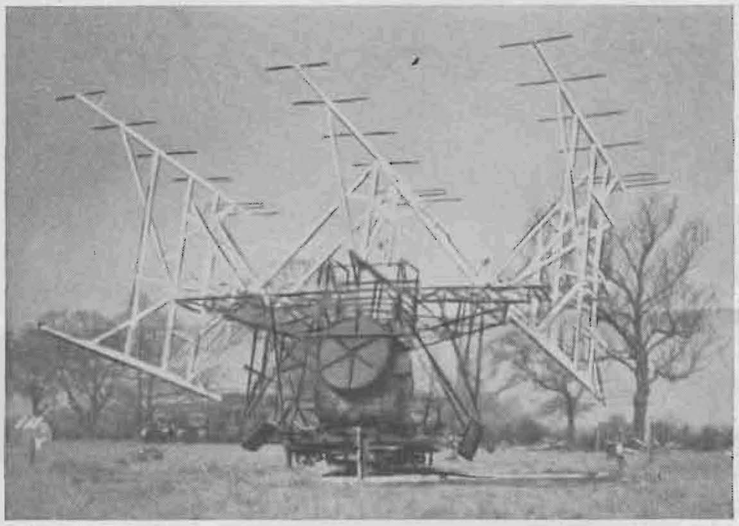

Fig. 3—A Yagi antenna mounted on army searchlight scans sky.

The receiver is a normal superhet with grounded-grid triodes in the first two stages to give maximum sensitivity. The i.f. is at 10 mc, and has a bandwidth of 1 megacycle. Negative pulses can be applied to the suppressors of three of the five i.f. tubes to suppress the receiver during the transmitter pulses, and to blank out unwanted echoes from the local hills.

Both transmitter and receiver are connected to the same aerial system with a spark-gap switching arrangement. Sometimes a simple dipole aerial is used, but more often it is the array of Yagi elements mounted on an old army searchlight shown in Fig. 3. This gives a beam of ±10 degrees width, and can be pointed at any part of the sky. The output of the receiver is displayed on an A-scope display, which can be seen in Fig. 4. It also goes to an automatic recorder which will be described later.

A photograph of a typical echo from a meteor trail is shown in Fig. 5. The number of meteors seen with this apparatus is close to that seen by a visual observer under good dark sky conditions, and is normally from 2 to 10 per hour. When the showers occur the hourly rate rises to 50 or 60 for several nights in succession. During a remarkable event on October 10, 1946, it increased by 5,000 times to 160 per *minute* between midnight and 3:30 a.m. On this occasion the earth passed close to the Giacobini-Zinner comet, and was bombarded for six hours as it crossed the orbit.

In similar piece of equipment on 73 mc, two fixed beamed aerials are used, each consisting of six Yagi elements, shown in Fig. 6. The signals from these two aerials are fed separately into two intensity-modulated displays and photographed on a continuously moving film. An echo from a long-duration meteor trail on this apparatus is shown in Fig. 7. The pulses are doubled for easy identification of the short-duration echoes against the noise background.

Such radio techniques enable observations to be made in daylight. Through this ability some striking discoveries have been made. The apparatus described above has been used at Jodrell Bank since 1946, and a remarkable sequence of intense meteor showers only active during the summer daytime was discovered in the summer of 1947.

Measurement of velocities

Perhaps the greatest hindrance to rapid progress in the study of meteors has been the very great difficulty of measuring the speed with which they enter the atmosphere. Since they are travelling at a speed of nearly 100,000 miles per hour, it is not surprising that this measurement has been hard to make. Without an exact knowledge of the speeds of meteors it is not possible to decide where they come from—nor even to decide whether they are all localized in the solar system or whether some come from interstellar space. It was therefore important to develop radio methods for velocity measurement. The one to be described was developed at Jodrell Bank and has been in regular use since 1947 for measuring these high velocities.

The radio echo seen on the apparatus described above comes from the completed electron trail of the evaporated meteor. The velocity recorder works by studying the echo from the trail *while it is being formed.* The apparatus measures the speed with which the electron trail is made. While the trail is being formed there are intensity fluctuations in the echo returned to the receiver which are exactly analogous to the fluctuations in the light near the edge of a sharp shadow on a screen—the familiar optical phenomenon known as diffraction. The fluctuations in amplitude to be expected as the meteor passes the per-

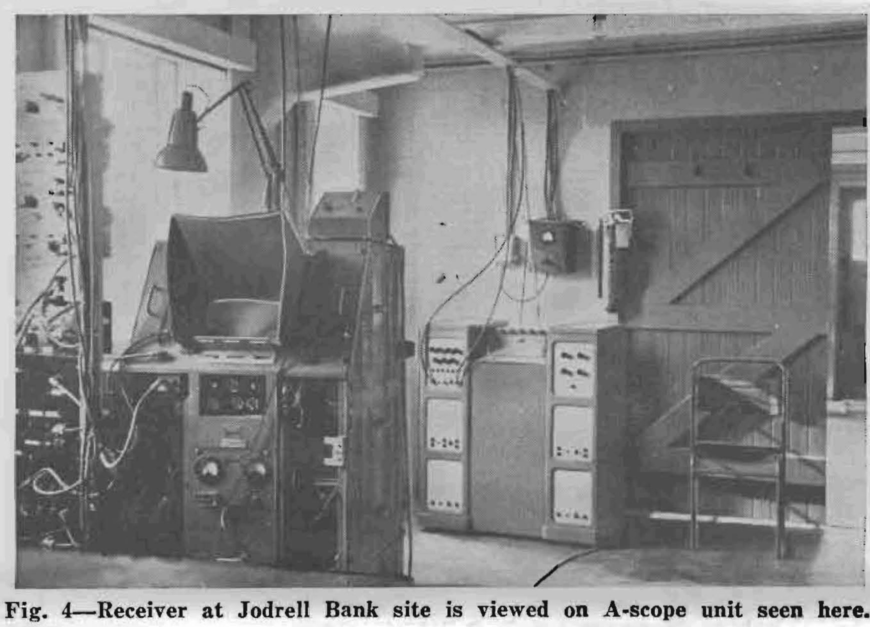

Fig. 4—Receiver at Jodrell Bank site is viewed on A-scope unit seen here.

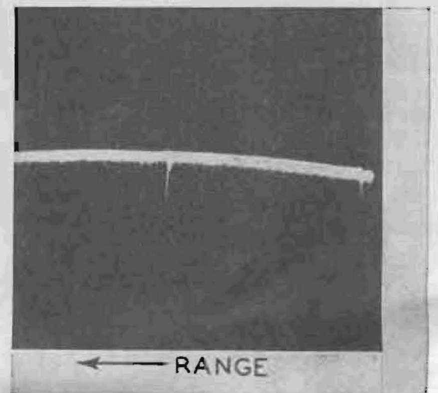

Fig. 5—A picture of a meteor trail.

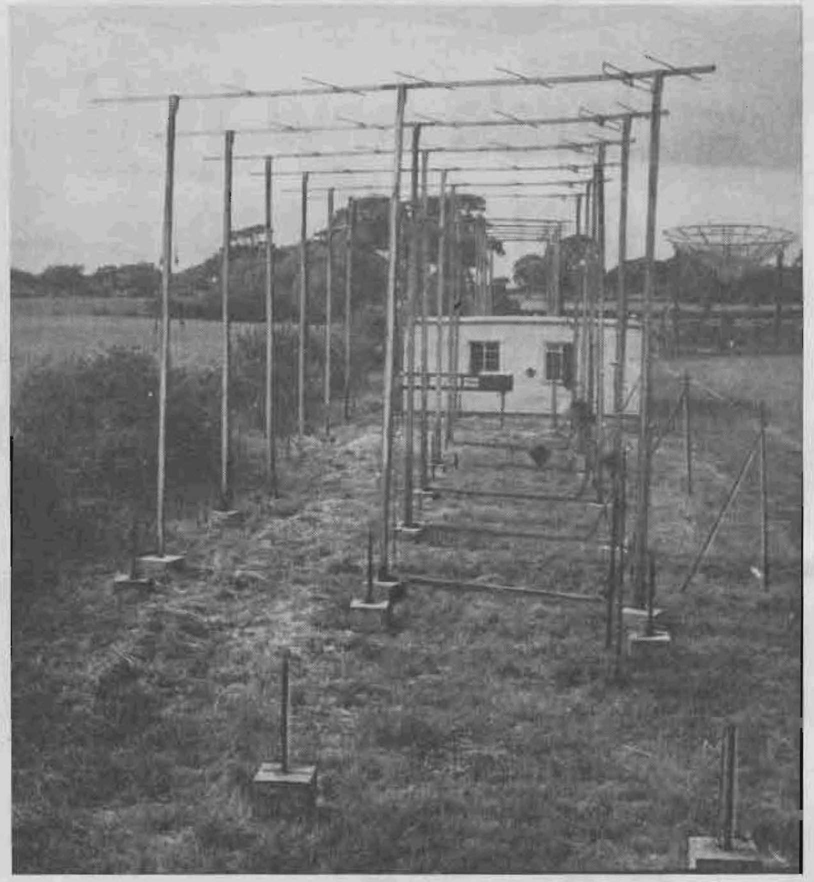

Fig. 6—Two fixed beam antennas are used on 73 mc, each having 6 Yagi elements.

pendicular point from the station to the trail are shown in Fig. 8. The horizontal spacings OA, OB, OC, etc., can be shown to be $1.2\sqrt{R\lambda}$, $1.9\sqrt{R\lambda}$, $2.3\sqrt{R\lambda}$. λ is known, the range R can be measured on an A-scope display. Hence if we can measure the time T_{AB} for the trail to form from A to B etc., then the velocity of the meteor is given by: AB/T_{AB} etc. The great difficulty is in measuring these time intervals. If typical values, $\lambda = 4$m, R = 300 km, are inserted, we see that OA is only about 1 km. But an average meteor is moving at about 40 km per second, hence the time interval between O and A is only of the order of 0.025 seconds or 25 milliseconds.

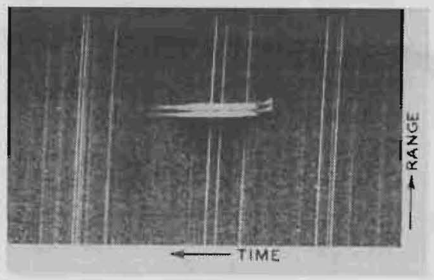

Fig. 7—Long duration meteor trail echo.

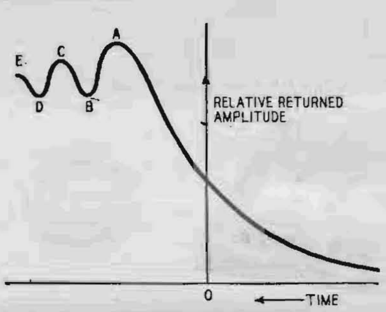

Fig. 8—Meteor position amplitude curve.

In the velocity recorder, which can be seen in Fig. 4, photographs are taken of two cathode-ray tubes, each with a single-stroke time base. One time base lasts for about 10 milliseconds, and is used to measure the range of the meteor by standard radar methods; the second time base lasts for 0.1 seconds, and displays the first 60 echo pulses received side by side. A photograph of these pulses appears in Fig. 9. The time bases are triggered simultaneously, by the first echo pulse received that is greater than a given amplitude—about twice the receiver noise level. The transmitter is pulsed at 650 pulses per second, so that the separation between pulses is 1-5 milliseconds. Thus the time intervals between the maxima and minima can be measured with great accuracy.

The recorder unit

A block diagram of the recorder is given in Fig. 10. The output from the receiver is fed to the cathode-ray tubes via an amplifier, and is also used to trigger the time bases via the discriminator unit. This unit is required to separate the echoes from impulses caused by atmospherics or ignition systems. Its operation will be described in detail below, and a schematic of the discriminator unit appears on page 54.

In addition, a set of relays is triggered from the discriminator. This flashes a light onto a clock, recording the time of occurrence, and, after the photograph has been taken, operates the camera motor and resets the instrument for the next echo. The direct signal from the transmitter, and the echoes from ground sources nearby, are removed by suppressing the receiver for the period during and immediately after the transmitter pulses.

The discriminator operates on the duration of a single echo pulse. This is equal to the transmitter pulse length, and is about 8 microseconds, while the duration of a single noise impulse is determined by the receiver bandwidth and is 2 or 3 microseconds.

The circuit diagram is given in Fig. 11, and the waveforms in Fig. 12. Tubes V1, V2, V3-a, and V4 form an a.v.c. amplifier with cathode follower output, the receiver noise at the cathode of V3-a being about 20 volts peak-to-peak, and positive in sign. V5 is a limiter stage, with about –20 volts bias on the grid. Hence it is normally cut off, but begins to conduct as soon as any signal rises much above the noise level. Grid current limits the signal at about twice the receiver noise level, producing waveform B (Fig. 12) on the plate of V5. V7 comprises the discriminator stage, in effect an infinite impedance detector circuit, and a cathode follower, the output from which is shown at C in Fig. 12. On the leading edge of the pulses, the first half—originally only passing about 150 microamperes—is cut off, and the cathode falls at a rate determined by its stray capacitance. On the return stroke, however, the tube conducts heavily, and hence returns very rapidly to its original potential. This is important, as interference caused by ignition systems frequently consists of a train of impulses with very little interval between them, and such interference could be confusing.

The effect of this circuit is first to reduce all impulses to the same amplitude, and then to give them an amplitude that depends on the duration

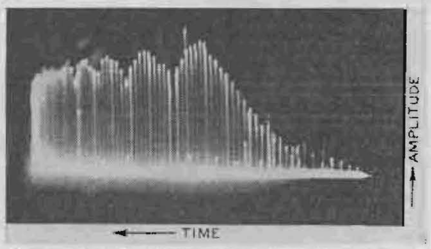

Fig. 9—Recorder unit time base photo.

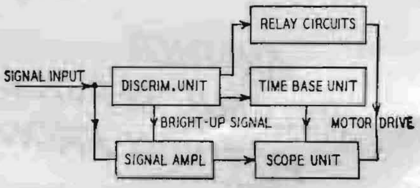

Fig. 10—Recorder unit, block diagram.

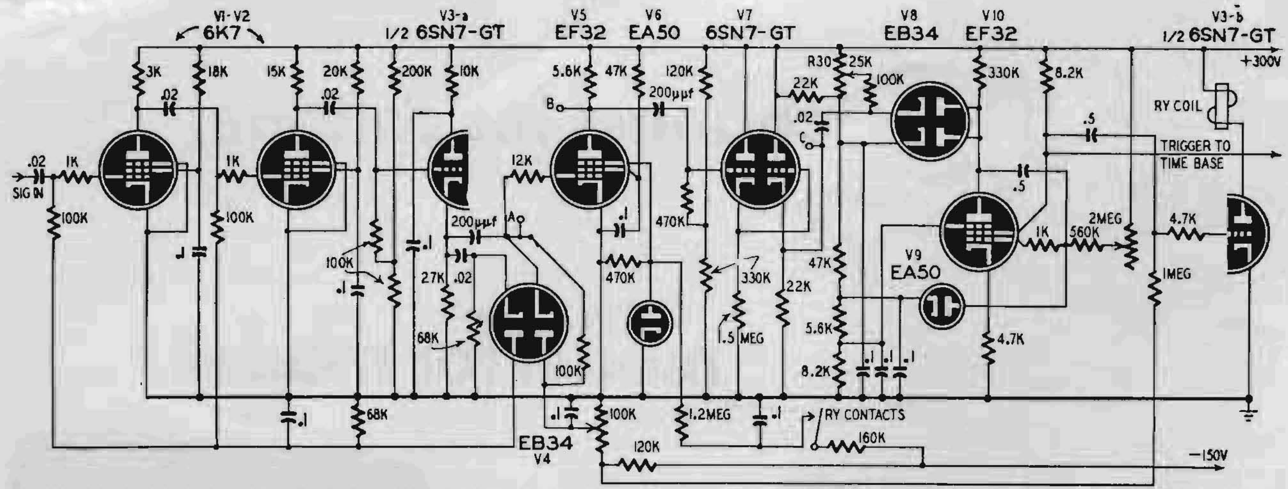

Fig. 11—The discriminator unit which detects the meteor echo pulses and passes them to the camera relay circuits.

of the pulse. The remaining circuit consists of a phantastron set to trigger on pulses greater than a certain duration (set by R30) which triggers the time-base circuits, and operates the relay coil RY. The contacts on the suppressor grid of V5 are closed by the relays, and prevent the circuit being retriggered until the camera is reset.

Many thousands of meteor velocities have been measured by this type of recorder, enabling great progress to be made in some of the fundamental problems of meteor astronomy.

Great use has been made by workers at Ottawa and Stanford of c.w. techniques for special purposes. For example, if c.w. is used, the above diffraction photographs appear as continuous records and more zones can be measured. This is especially true if the reflected wave from the trail is allowed to beat with a local ground wave. In this case the fluctuations can be seen before the perpendicular point O (Fig. 8), since a local reference phase is available before the perpendicular reflection takes place. Of course the range of the meteor has to be measured by using a subsidiary pulse apparatus. Incidentally these c.w. fluctuations can be heard as the so-called Doppler whistles, since the period of the oscillations lies in the audible range. Such whistles have been picked up by amateurs and can be heard easily if they can tune to an unmodulated carrier at several miles distance on a frequency of about 20 or 30 mc.

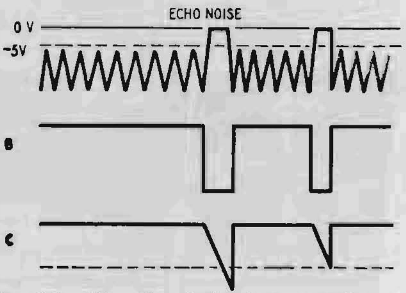

Fig. 12—The discriminator waveforms.

In this short article we have concentrated on describing some basic techniques used in the radio observation of meteors. The results obtained during the past few years have revolutionized the science of meteor astronomy. The work is also of very great interest in physics, since a new tool now exists for studying the conditions in the high stratosphere, and invaluable data is being obtained about such diverse subjects as upper atmosphere wind motions and the processes of ionization.

—end—

AN EXPERIMENTAL CHASSIS

Like most ardent experimenters, I never seemed to have a chassis which was punched just right for the circuit I happened to be building at a particular moment. Tiring of using the same old battered chassis for every experiment, I developed two small basic units from which larger chassis can be constructed. This setup has the following advantages: (1) Socket holes are always where I want them; (2) wiring can be systematic with easy access to A-, B-, and ground leads; and (3) the chassis can be used for breadboard experiments or for a finished product.

The drawing shows the shapes and sizes for the basic units. The U-shaped socket strip is punched in the top for a socket and in one side for two potentiometers or similar controls. An eight-point mounting strip is located close to one side of the socket strip to support power leads which run the length of the completed chassis. Each socket strip has three small angle brackets on each open side. These brackets are aligned so the strips can be bolted together or to the end pieces.

The end pieces have 10 holes for mounting pilot lamps, insulated jacks, plugs, terminals, and rotary switches. Two additional mounting holes are provided for toggle switches. The bend in the end pieces makes a steady support for the chassis when upside down.

The photos show an amplifier constructed on the chassis and the end piece and socket strip.— *Otto von Guericke*